Flip-Chip Ultralow Residue Fluxes

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Semiconductor / Packaging Soldering Paste / Flux Roadmap

	Wafer solder bump pitch (µ)					Cu pillar pitch (µ)		
	180	150	125	100	70	40	30	20
Wafer/interposer WS paste (Print)			2014	?	x	x	x	x
Bump fusion WS flux (Spin coat)							2014	2016
FC attach WS flux (Dip, spray)			2014	?	x	x	x	x
FC attach NC flux (Dip, spray)							2014	2016
	BGA ball pitch (mm)							
	0.5	0.4	0.3	0.24	0.2			
BGA WS flux (Pin transfer, print)			2014	2016	2018			

Packaging Level Flux Requirement

- Dippable or sprayable for I/O up to more than 10,000, pitch < 100 µ & bump size < 50 µ
- Flux heterogeneity diameter < 1/3 of smallest feature size
- Flux should be tacky to hold to chip, and preferred to be liquid to be washed easily after reflow
- Flux should not react with passivation layer to minimize potential of die cracking
- For ball mounting, the rheology should accept ball easily at placement, and hold the ball well at reflow
- Allow good wetting & low voiding between solder and Cu or Au or other surface finishes
- Flux residue cleanable with solvent or water (favored)
- If no clean, need to be compatible with underfill

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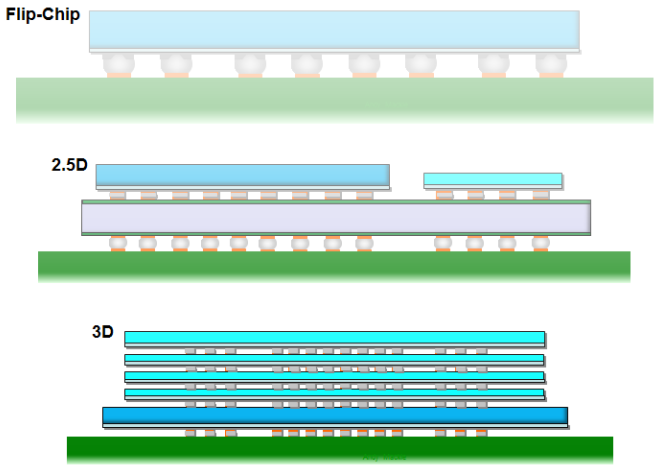
Drives Toward No-Clean

- **Package Design Changes…**
  - Pitch shrinking to 100microns and below
  - Die-substrate clearances down to 60microns and below
  - Substrates thinner and subject to warping
- **…Causing Flux Cleaning Challenges:**
  - Pitch reduction limits ability to completely remove flux residues:
    - Corrosive residues left behind
    - Block flow of CUF and MUF leading to voiding
    - Interfere with CUF and MUF adhesion causing delamination
  - Cleaning process:
    - Adds costs
    - Increases substrate warpage after reflow and before underfill, leading to cracked solder joints



Answer:

- Move to no-clean flux

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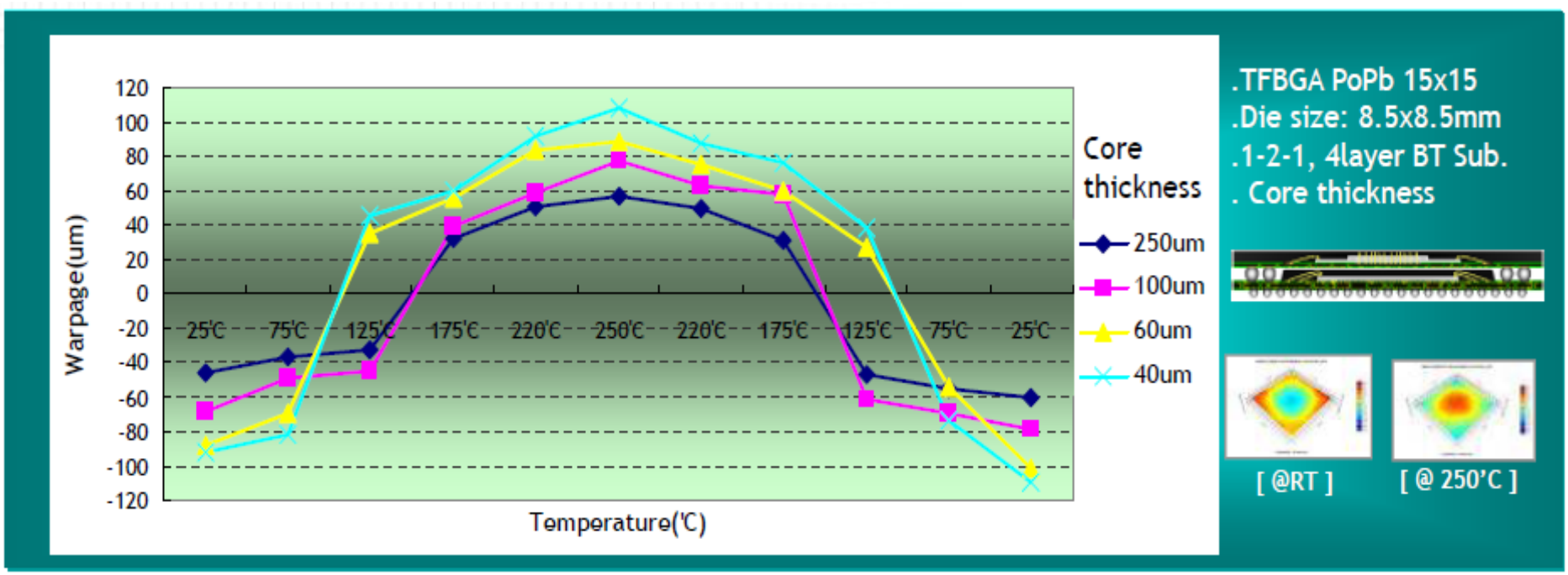
Substrate Warping Challenge
Cleaning leading to cracked solder joints



Increased substrate warpage in reflow: due to reduced substrate thickness

Taken from: K. Lee, "Mobile platform packaging challenges," iNEMI workshop, Nagoya, Japan 2009, pp. 9 and 10

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Flip-Chip Flux: Criteria for Dipping / Mass Reflow

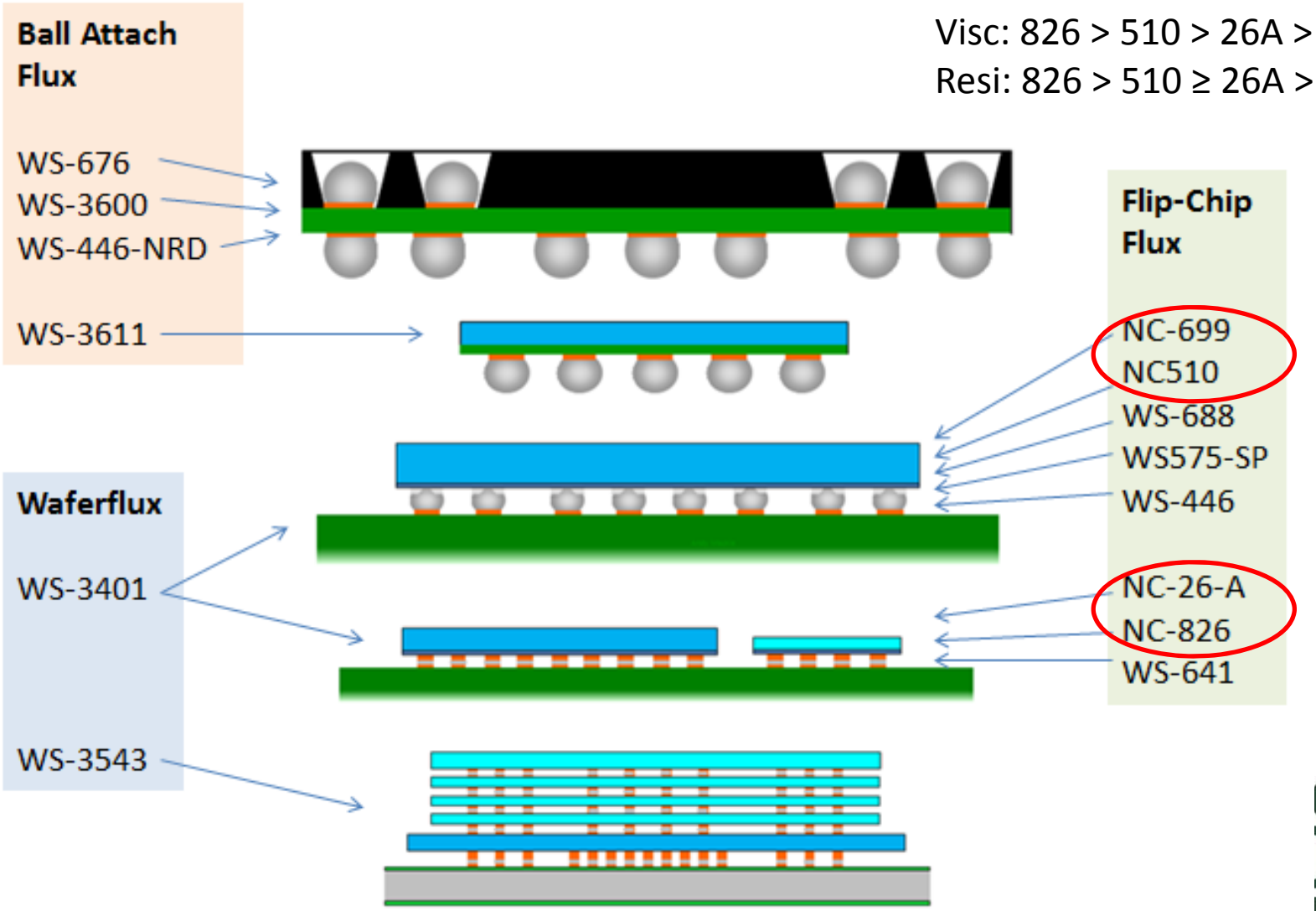
	No-Clean			Water Wash
Flip-Chip Performance Criterion	Standard Residue Flux	Flip-Chip Flux LR & ULR flux	*Near Zero Residue (NZR) Flux***	Water Soluble Flux (perfectly cleaned)
Solder joint yield				
Excessive CUF epoxy bleedout				
CUF and MUF voiding				
Potential for flux/underfill (CUF and MUF) delamination				
Assembly process cost				
Pick up small die from flux dipping tray				
Hold large die in place for mass reflow				
Flux bridging with fine pitch bumps / copper pillar				
Flux contaminating die surface after reflow				
Solder joint cracking: between reflow and underfilling				
Suited for low clearances (<60um) and <100um pitch copper pillar				

***Designed for TCB*

Known problem	
Area of concern	
Known solution to problem	

Semiconductor Fluxes: Major Commercial Usage Q4 2014

Visc: 826 > 510 > 26A > 699
Resi: 826 > 510 ≥ 26A > 699



NC-826

NC-826

- Characteristics
  - High tackiness.
  - Preventing skewing/departing chip with small copper pillar (<100micron) in the process of placing chip.
  - Higher residue (7~8%) than Flip Chip Flux 026A.

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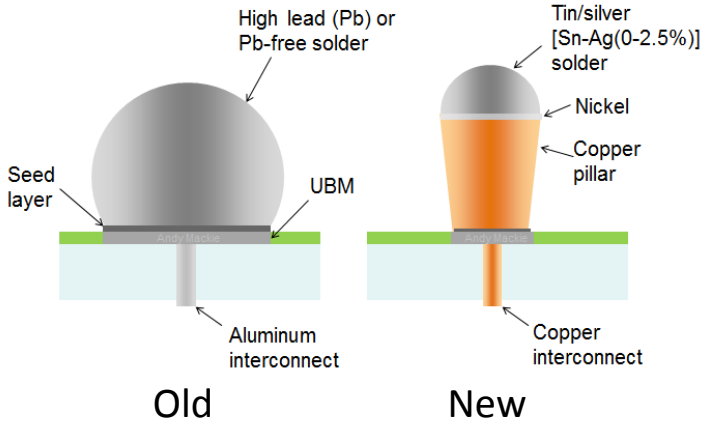
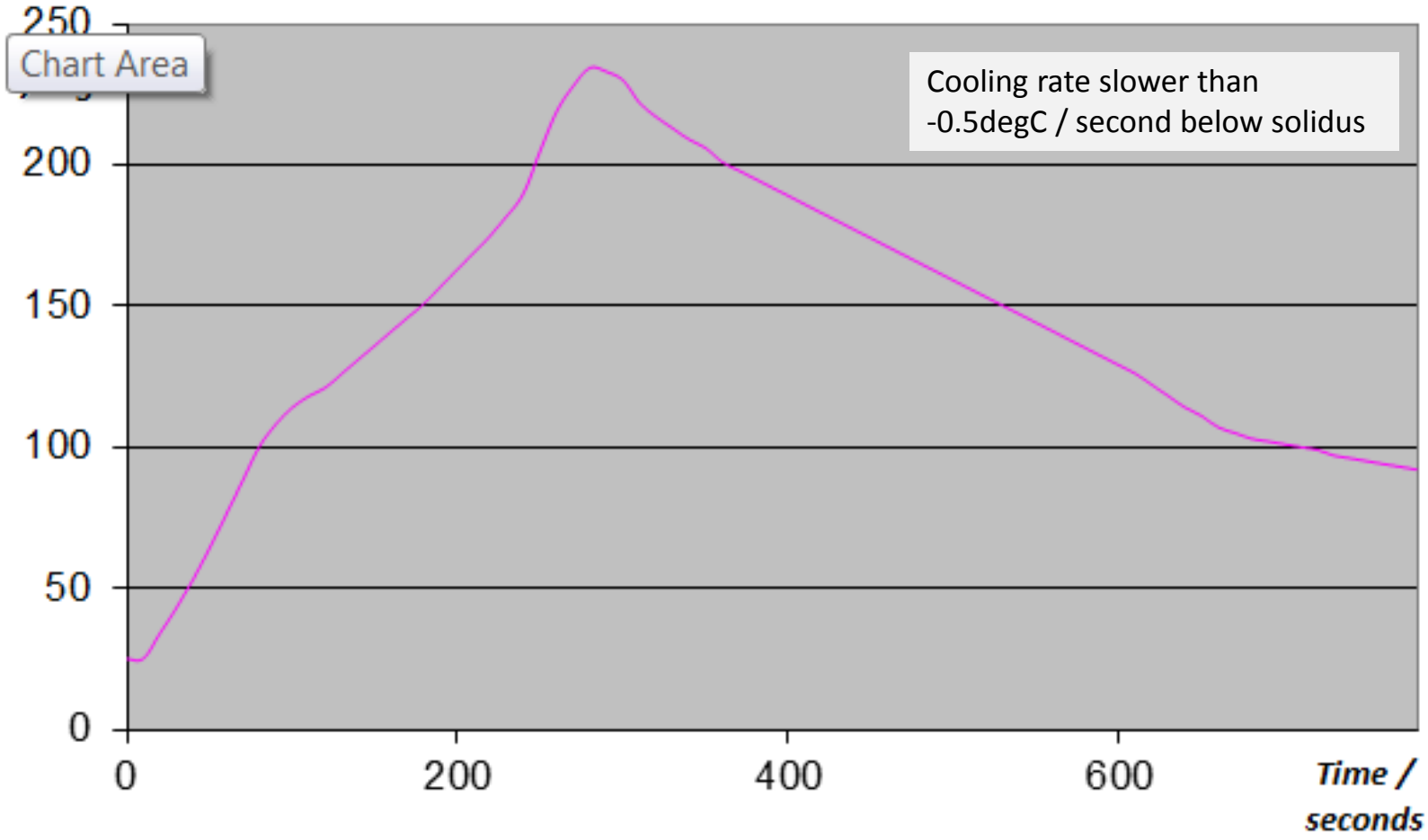
Flip-Chip Flux NC-826 Product-Specific Attributes

- High yield soldering to copper OSP
- Designed for copper-pillar
- Dipping with minimal bridging
- No wetting onto die surface
- Holds large die in place during reflow
- Residue compatible with CUF and MUF without delamination

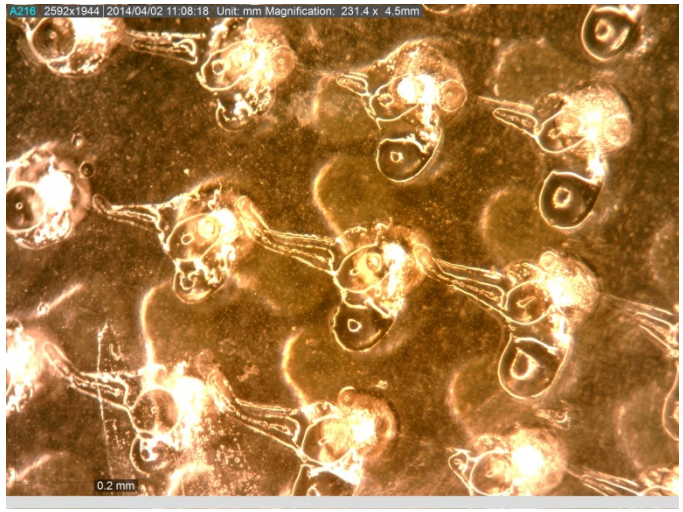


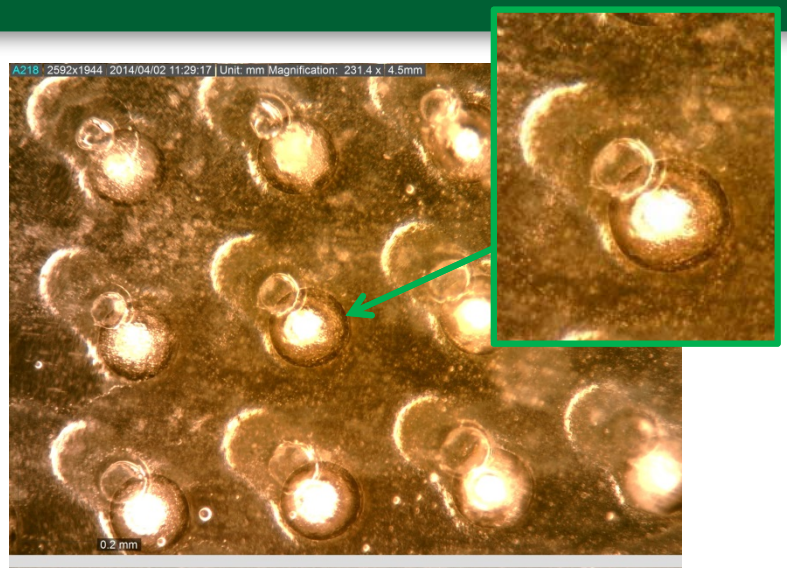
Typical Reflow Profile <100ppmO_2



Residue Level: NC-826 and Standard Residue Flux

Standard Residue Flux

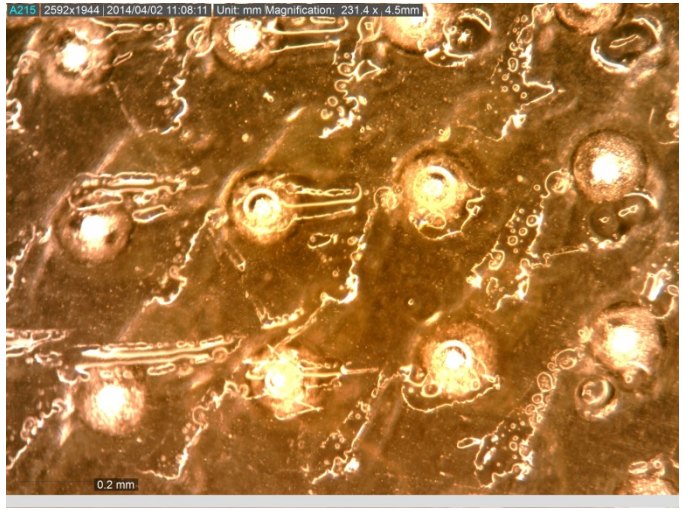


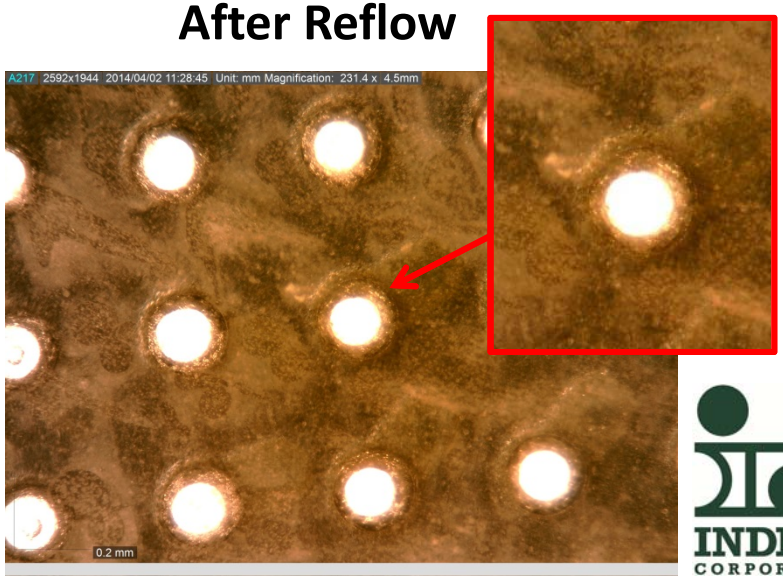


Before Reflow

After Reflow

Ultralow Residue Flux





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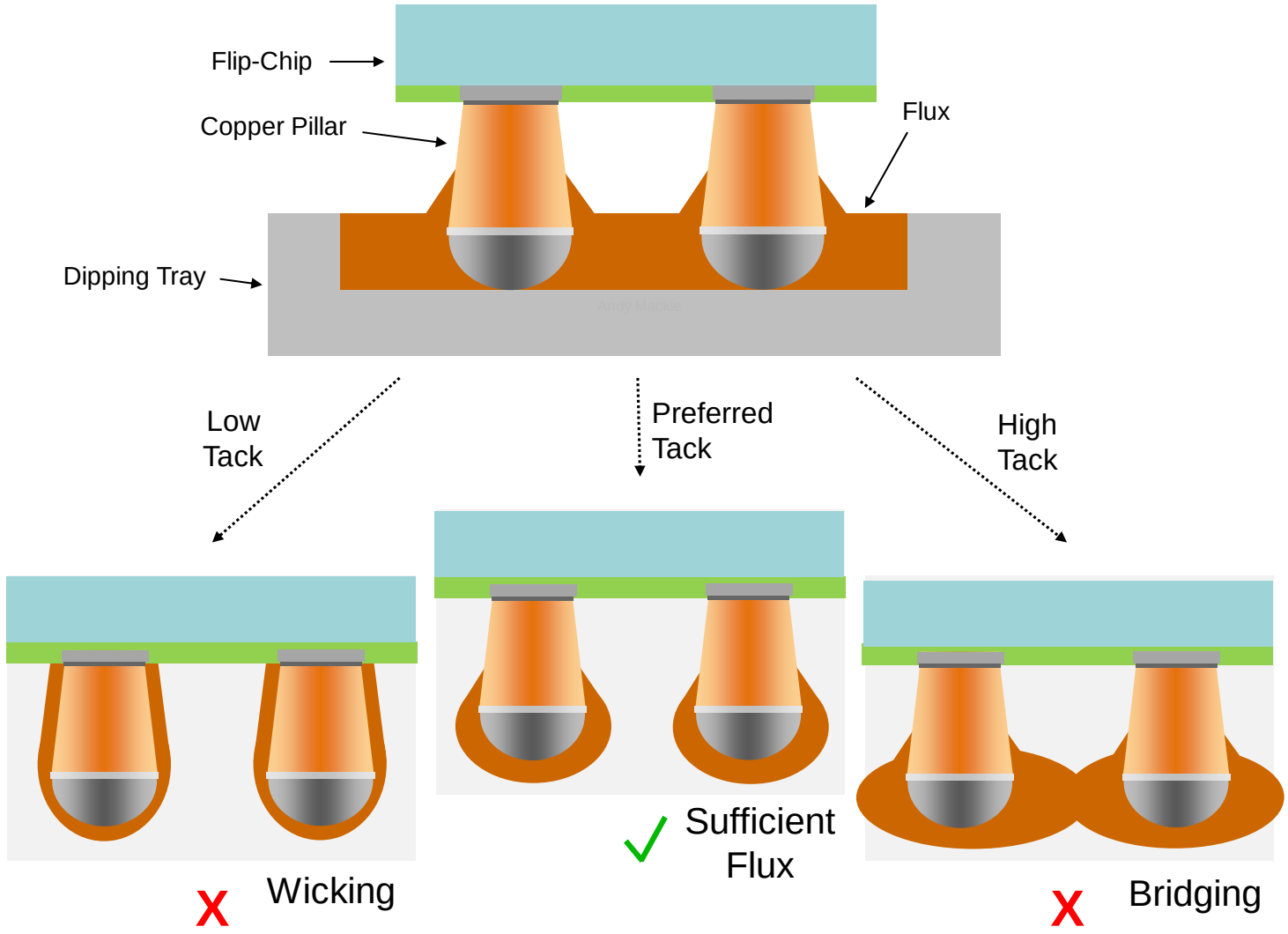
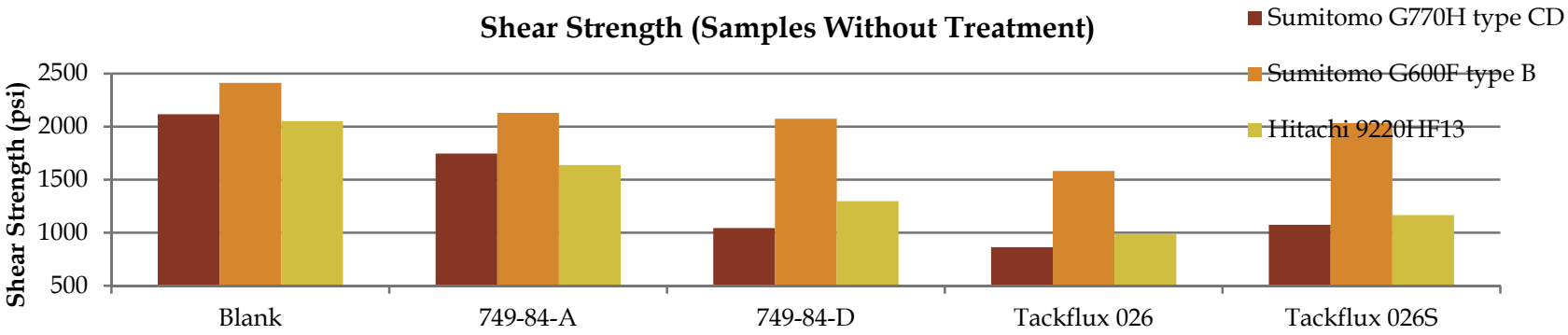
Rheological Design for Dipping: Flip-Chip Flux NC-826

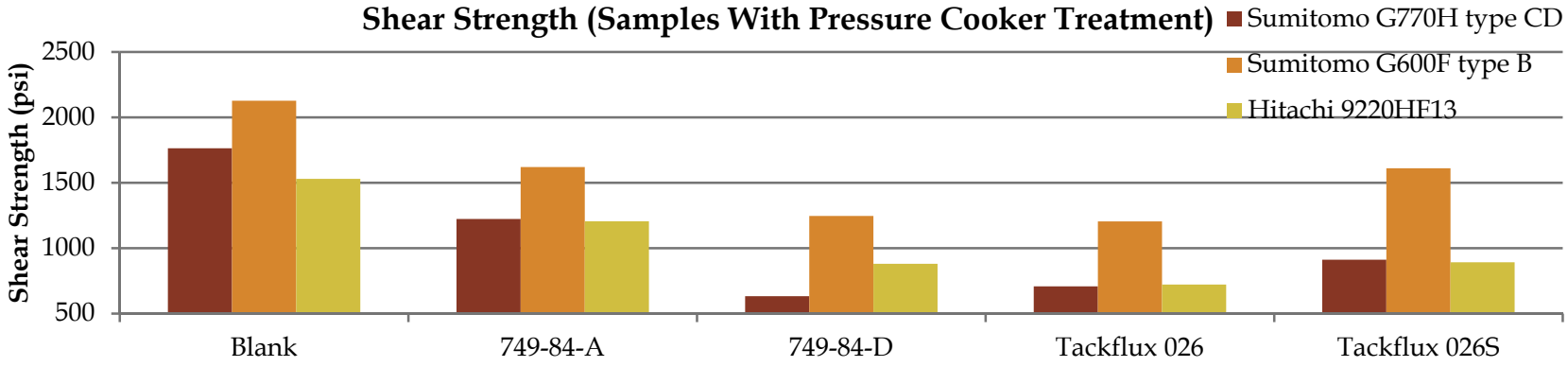


Tacflux 26 & 26S

Underfill Compatibility
Tacflux 26 & 26S

Compatibility Test



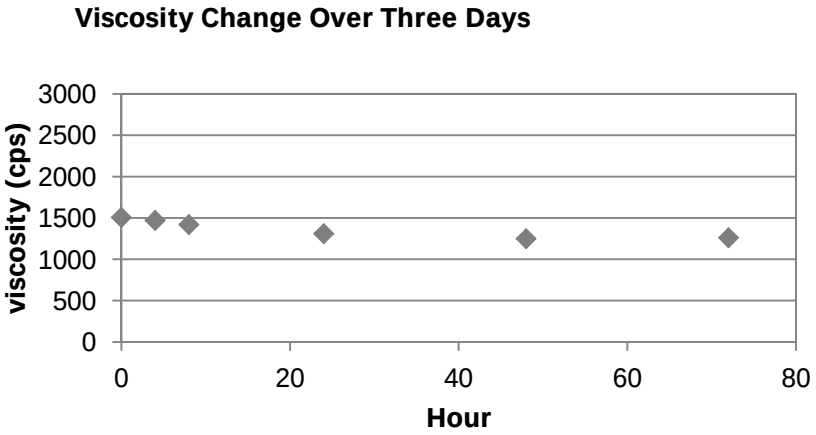


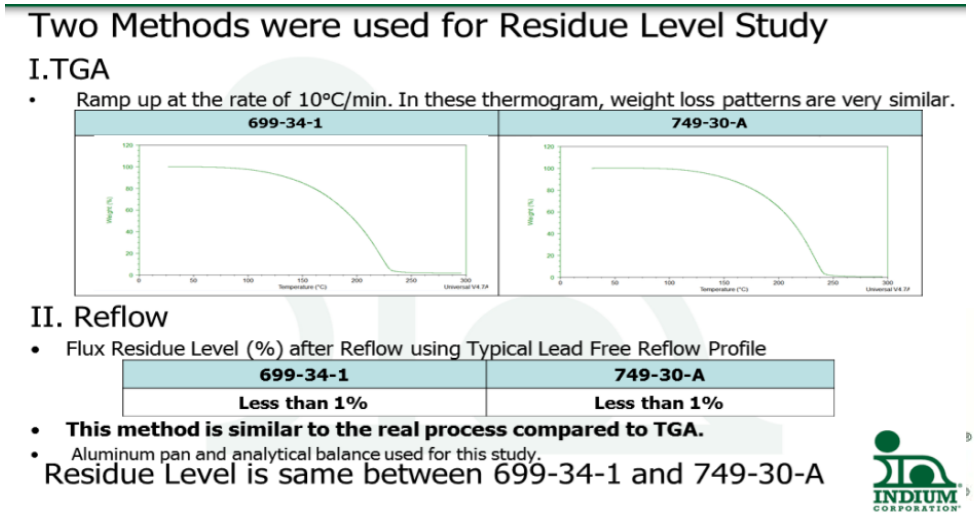
- In Tacflux 026S and Tacflux 026, Tacflux 026S provides better compatibility.

NC-699

NC-699

- Characteristics
  - Residue level is less than 1%.
  - Preventing skewing/departing chip with small copper pillar.
  - Below data are viscosity change over three days and Residue study.
  - Passing HAST and 1000 TCT requirements.





NC-26A

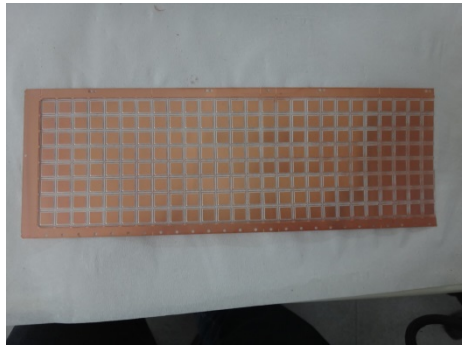
NC-26A and Under-fill compatibility study

- Background:
  - To test the NC-26A Flux and Under-fill compatibility to full-fill customer process requirement.
- Experiment:
  - Three NC-26A Flux and under-fill (provided by customer) are tested on the Cu-Lead Frame and Glass substrate.
  - Other process tools: Hot plate, ultrasonic cleaning and SEM are prepared and used as page-3
  - The test condition and procedure as page-4/5.
  - Thermal cycle (125C/ 65C) test for 10 cycles was done by using two hot plate as page-6.
- Result:
  - The test on Cu-Lead Frame surface and Glass substrate show good compatibility between NC-26A Flux and under-fill on visual and Scotch tape test page-4/5.
  - The SEM cross section are checked and no delamination issue Page-7/8.
  - Post thermal cycle SEM data as page-7/8 mark in red.

Sample and preparation

- The test sample and tools are prepared as below:

Under-fill and NC-26A Flux



Cu Lead-Frame

Glass

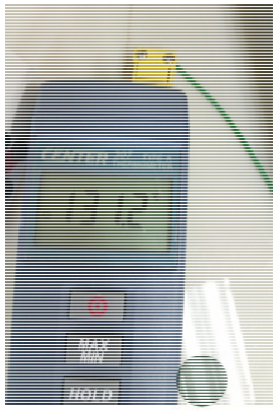
Die

Scotch tape

Ultrasonic cleaning

Hot plate

SEM



Thermal couple

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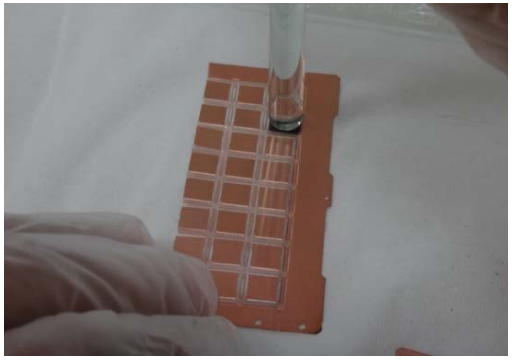
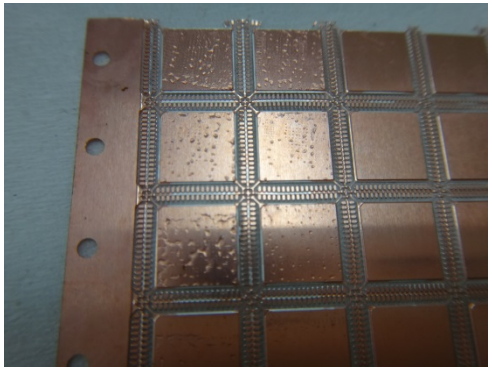
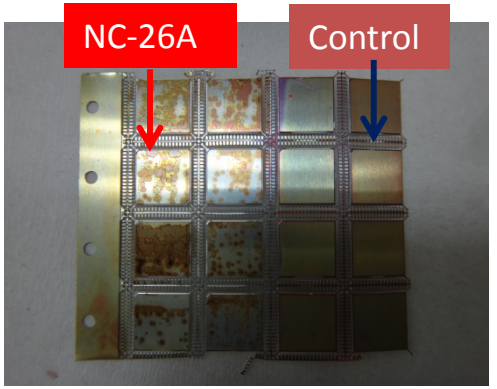
Test Run NC-26A vs Under-fill-1

Both with and without Flux Cu Lead Frame show good compatibility with Under-fill

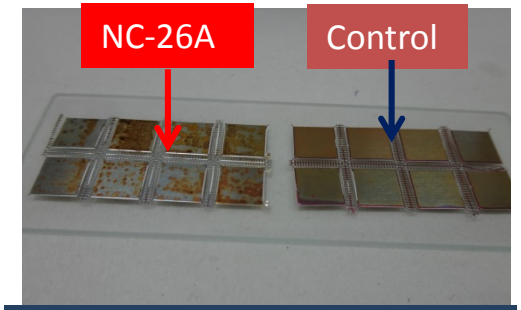




Transfer the Flux onto the Cu lead-frame

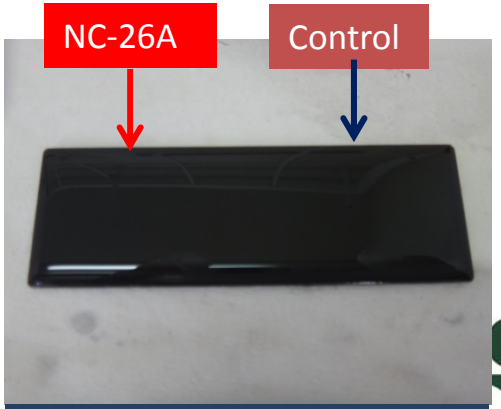


Hot plate 240C



Left: with Flux
Right: no Flux as control

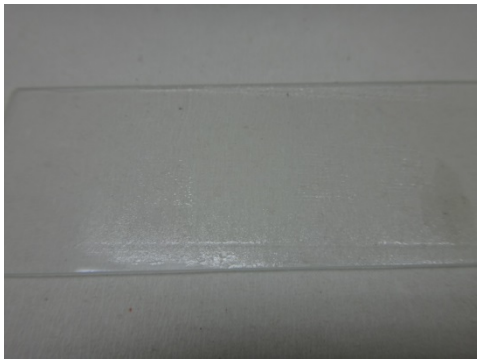
Under-fill curing



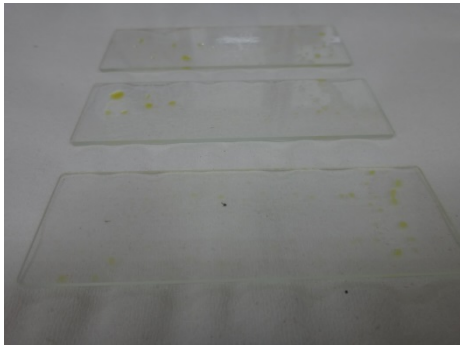
Visual check/ Scotch test are good

Test Run NC-26A vs Under-fill-2

Both Flux Thin Film and Flux Dot show good compatibility with Under-fill

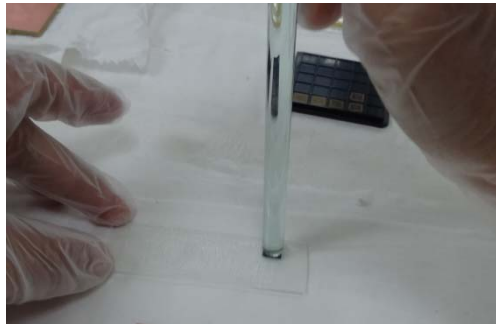


Thin Flux film

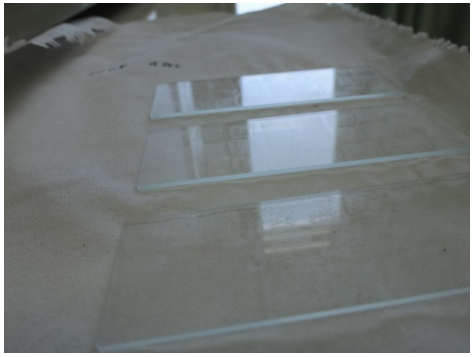


Post Hot plate 240C

Visual check/ Scotch test are good



Flux Dot by actual Die

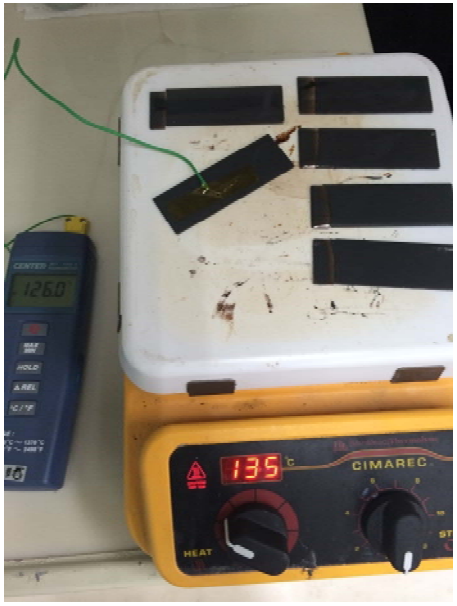


Post Hot plate 240C

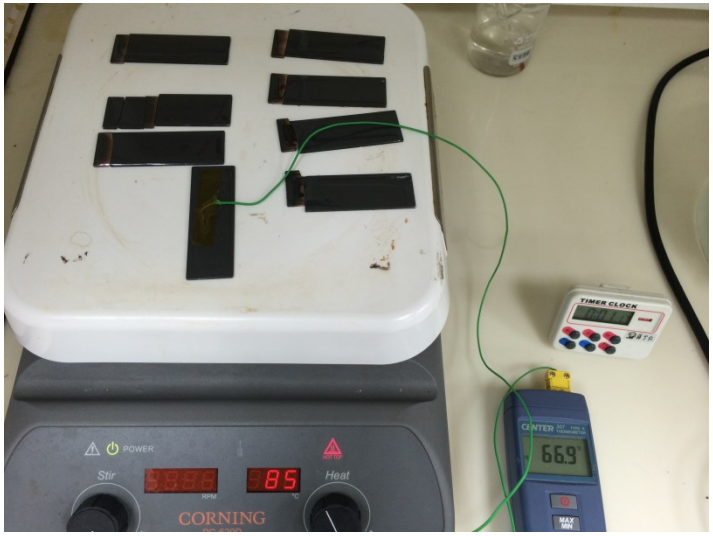
Visual check/ Scotch test are good

Thermal cycle -update

The thermal cycle condition is 125C/ 65C x10 cycles by using two hot plate to heat-up



10 cycles

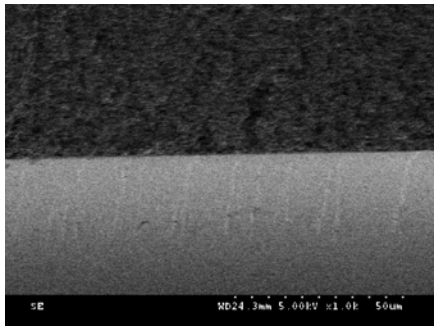


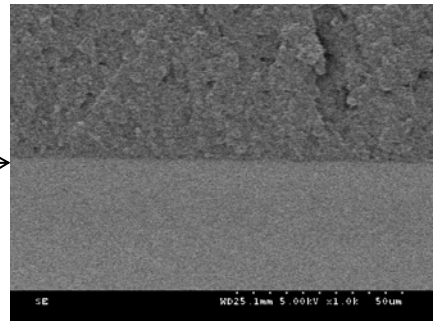
Heat-up to 125C
and stay 1.5min

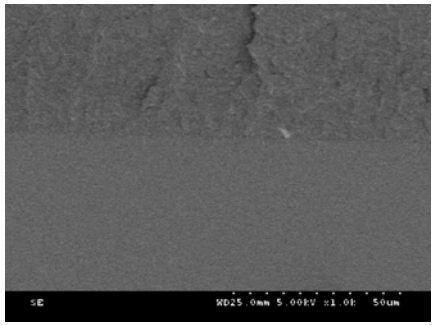
Cool down to 65C
and stay 1.5min

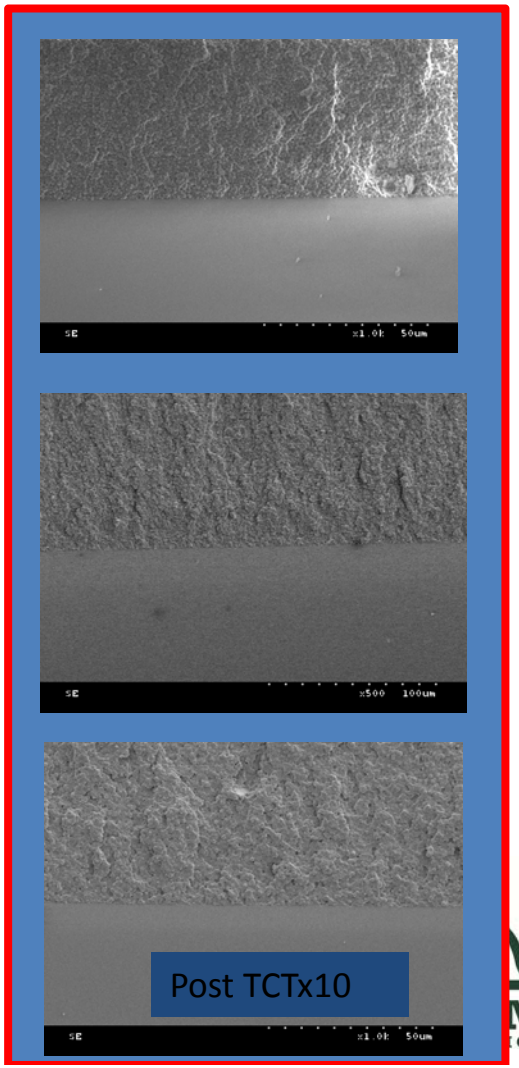
SEM X-section check on Flux Dot

SEM X-section check show good compatibility. No delamination in the interface.



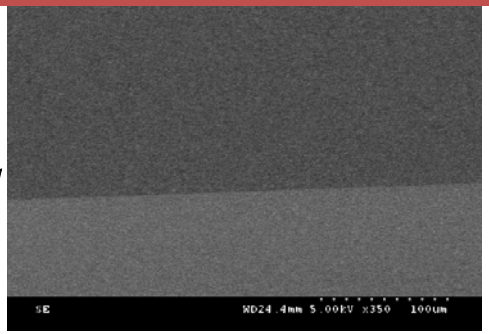


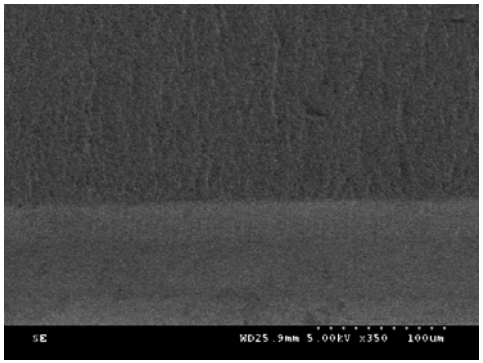


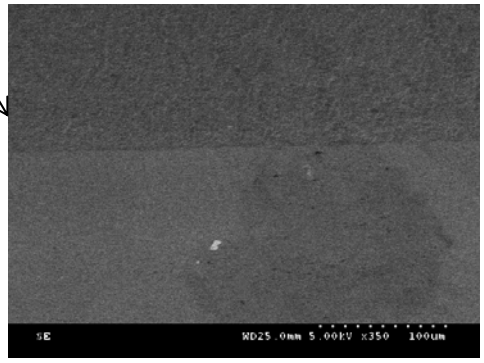


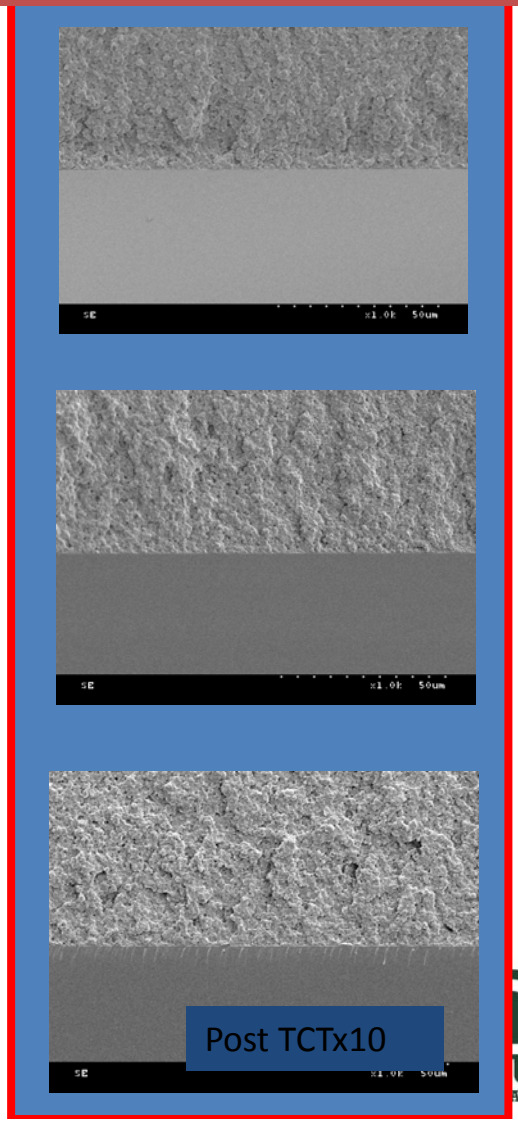
SEM X-section check on Flux Thin Film

SEM X-section check show good compatibility. No delamination in the interface.









Wetting Performance of Mitsui Lead Frame with and without Pre-cleaning Process

NC-26A

Introduction and Content

- There are two types of lead frames having different levels of oxide. One is from Shinko having low oxide and the other is from Mitsui with high oxide on the surface.
- High oxide lead frame (Mitsui) requires strong flux. Meantime, low oxide lead frame requires proper fluxing power to avoid the bridging of solder bumps.
- Since flux cannot have high and low fluxing power in same time, other property should be adjusted to make both lead frame works.
- Pre-cleaning process of Mitsui lead frame can remove the copper oxide.
- This work was done to demonstrate that pre-cleaning process could be applicable to ASE.

Contents

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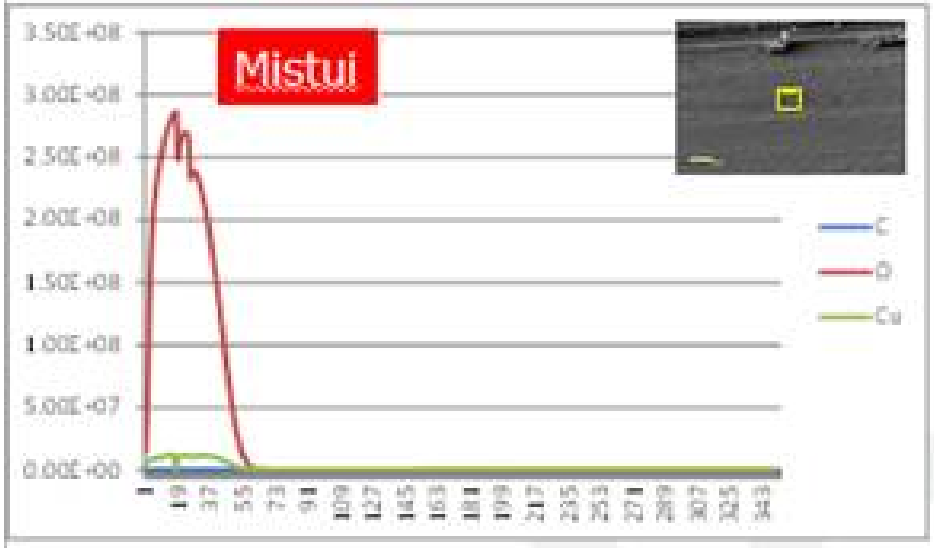
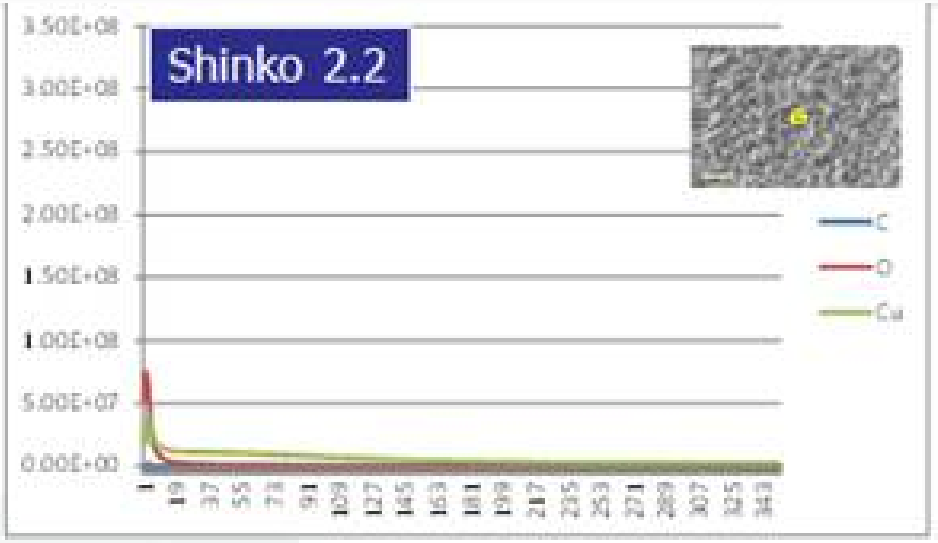
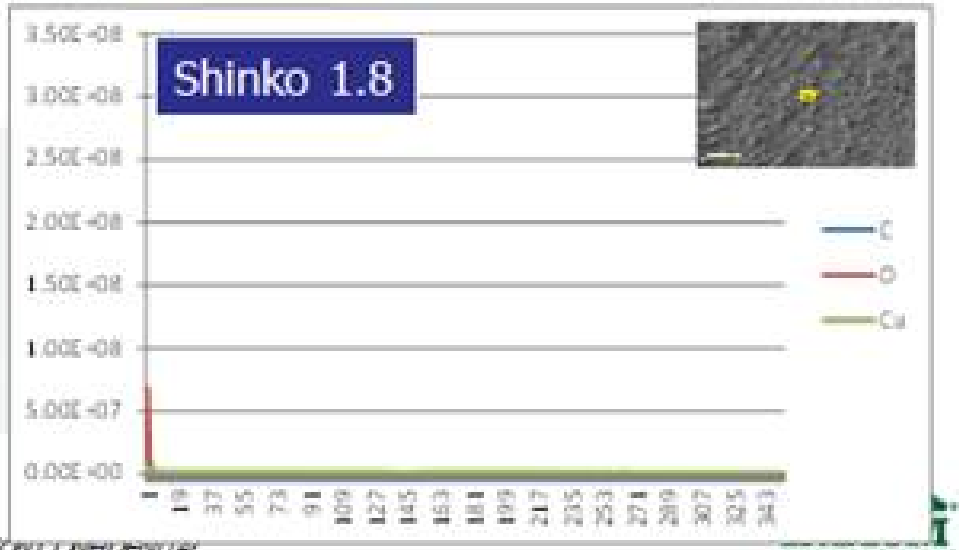
SIM Data







- Mistui leadfram had thick and high concentration CuO compare to Shinko

Experimental

- Pre-cleaning method

Mitsui copper lead frame was cut and immersed into 10% HBF_4 in H_2O for 10 minutes at ambient temperature (around 21°C). This lead frame was cleaned by large quantity of deionized water and then with IPA.

- Wetting Test

SAC 305 solder spheres (2.3mm diameter) were dipped with 0.26mm depth of Flip-Chip Flux NC26A flux. Two spheres were placed on each Lead Frame. These were reflowed using BTU convection oven with typical Pb-Free profile under N_2 environment (less than 50ppm O_2 level).

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Result and Discussion I

- To evaluate the effect of pre-cleaning of lead frame, one was used as itself, which has oxide on and another one was treated with acidic solution, 10% HBF_4 solution in water. These are referred as 'not cleaned Lead Frame ' and 'pre-cleaned Lead Frame', respectively.
- Below table shows the result of wetting. In sphere spread diameter, higher number is better in wetting due to more spreading. Meantime, in sphere height, higher number is worse in wetting.
- 'Not cleaned Lead Frame' showed 2.5 mm of sphere spread diameter which is close to sphere's original diameter, 2.3mm.
- On the other hand, 'pre-cleaned lead frame' provided good wetting.
- Sphere height agrees sphere spread diameter result.

Table Solder Sphere Spread (mm) after reflow.

	Sphere Spread Diameter	Sphere Height
Not Cleaned Lead Frame	2.5	1.74
Pre-Cleaned Lead Frame	4	0.84

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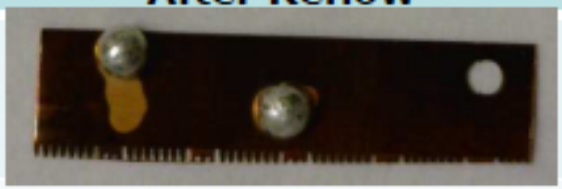
Result and Discussion II

- Below Pictures show the wetting test result of these lead frames.

Picture. Lead frame from Mitsui and its wetting performance

	Before Reflow	After Reflow
Not Cleaned Lead Frame		
Pre- Cleaned Lead Frame		

- Pre-cleaning process on Mitsui lead frame can enhance the wettability and this allows solder wet on Mitsui Lead Frame with Flip-Chip Flux NC26A .

- Pre-cleaning condition can be varied by the customer's preference such as equipment and chemistry. In ICA located in NY, 10% HBF_4 in H_2O was chosen because this was effective enough and available in wet laboratory.

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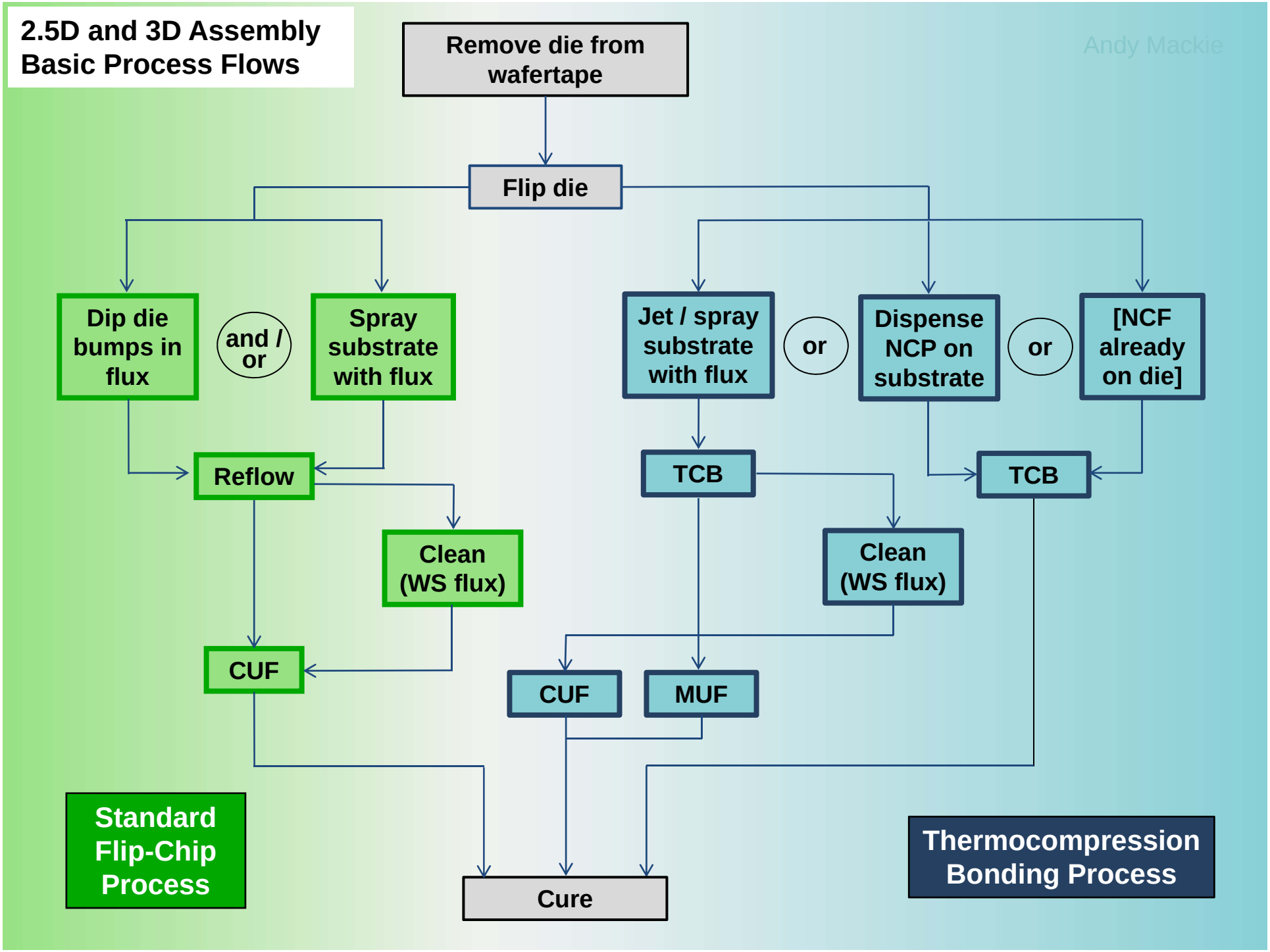
749-59-B

TCB


2.5D and 3D Assembly
Basic Process Flows
Andy Mackie
Remove die from wafertape
Flip die
Dip die bumps in flux
and / or
Spray substrate with flux
Jet / spray substrate with flux
or
Dispense NCP on substrate
or
[NCF already on die]
Reflow
TCB
TCB
Clean (WS flux)
Clean (WS flux)
CUF
CUF
MUF
Standard Flip-Chip Process
Thermocompression Bonding Process
Cure

TCB Concerns with NCP (NCF)

Concern	Description	Potential Causes
Throughput	Units per hour (UPH)	Time of NCP precision dispense; precision placement of die into viscous paste; TCB heat profile time
Voiding	Bubbles in the NCP	Flux reaction products; poor dispense or die-placement process; bubbles in NCP before application
Bridging (“extrusion")	Solder connecting adjacent joints	Overpressure during bonding process; no z-axis control; bubbles in NCP
Slippage	Die misalignment during placement	Radially asymmetrical force in the thinning TCB film; inability of bondhead to retain die alignment to head
Fillet unevenness	Wetting of NCP onto edge of die varies	NCP dispense pattern; uneven die singulation; radially asymmetrical NCP
Particulate entrapment in solder joint	NCPs all contain solid particulates	Simple capture of particles or particle flocs in solder joint
Unreliable solder joints	Non-wet opens and incomplete wetting of solder onto metallization	Warpage before or during bonding; non-isobaric compressive force; particle flocs blocking solder joint formation; insufficient pressure during TCB process
Damage to ELK/ULK layers	Thinned die at smaller nodes	Non-isobaric TCB process; high speed die-placement

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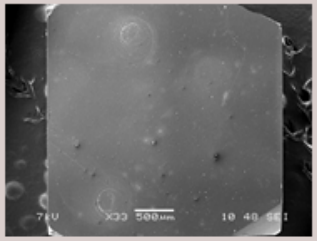
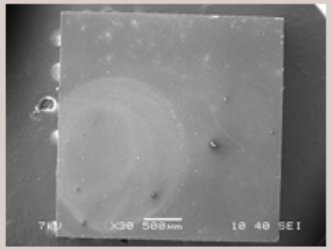
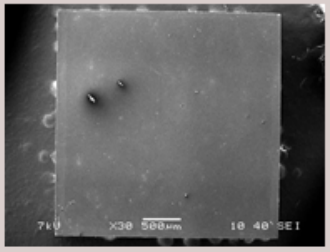
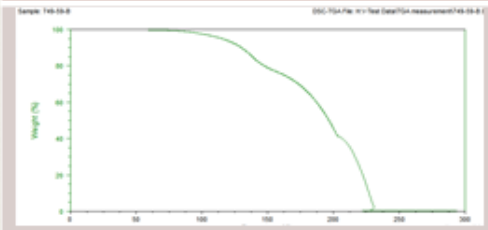
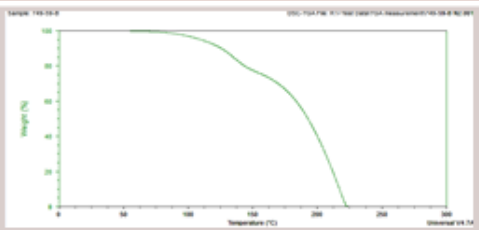
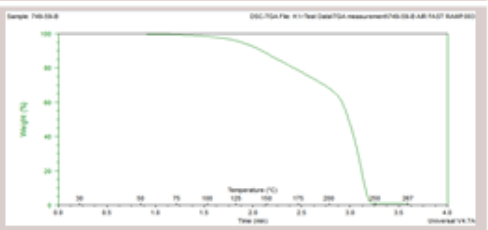
749-59-B Sample Testing Stage

- 749-59-B is developed for Thermocompression bonding.
  - Very low residue (<0.1%) after post heat treatment.
  - Weak wetting but improved compatibility between epoxy/flux residue
  - This flux is good for Thermocompression bonding but not other process.
  - Below test is TGA and SEM of chip after heat treatment

	Reflow N2	Reflow Air	Reflow Air/no flux
over all			

There is trace of flux residue but not easy to find on the surface of chip.

Air 10C/min	N2 10C/min	Air 75C/min
		

There is very little flux residue on TGA.

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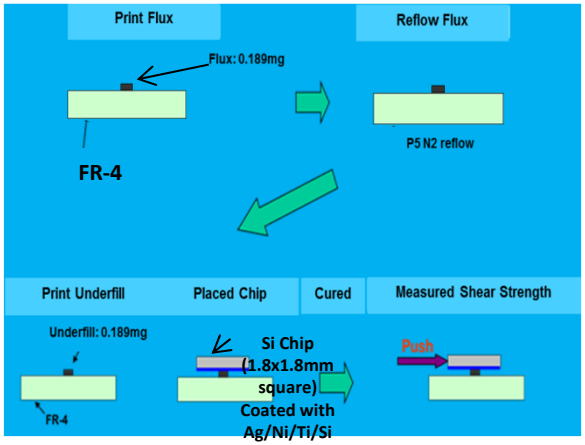
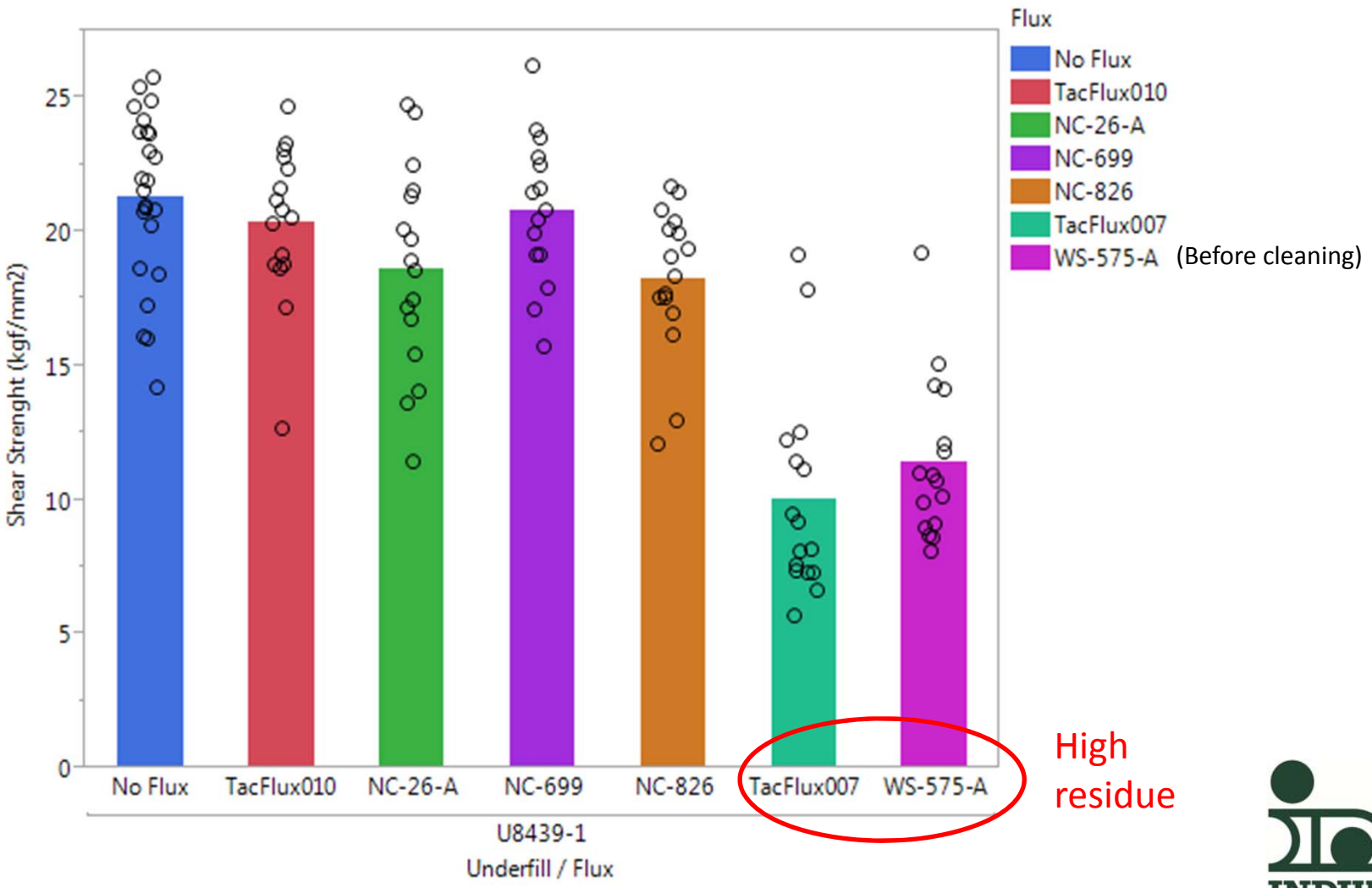
Comparison of ULR Fluxes

CUF / MUF Compatibility: Test Method

- Printing flux on FR4 (volume 0.19 mm^3)
- Reflowed in nitrogen with profile using
  - Oxygen level
- Printed underfill on FR4 (volume 0.19 mm^3)
- Placed die (Ag/Ni/Ti/Si)
- Cured according to recommendations
- (pressure cooker 1 day)
- Die shear testing



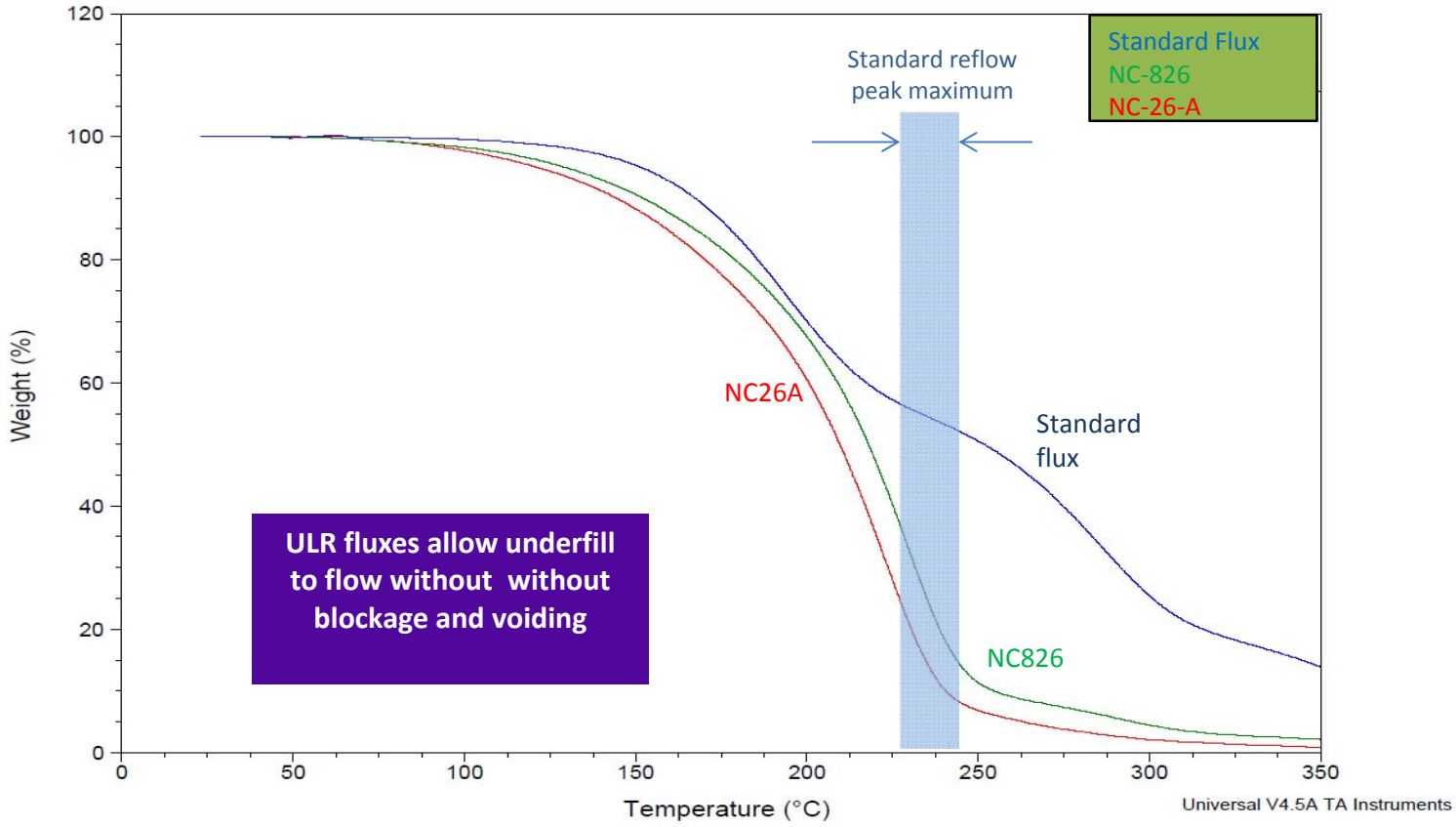
CUF / MUF Compatibility: Shear Results



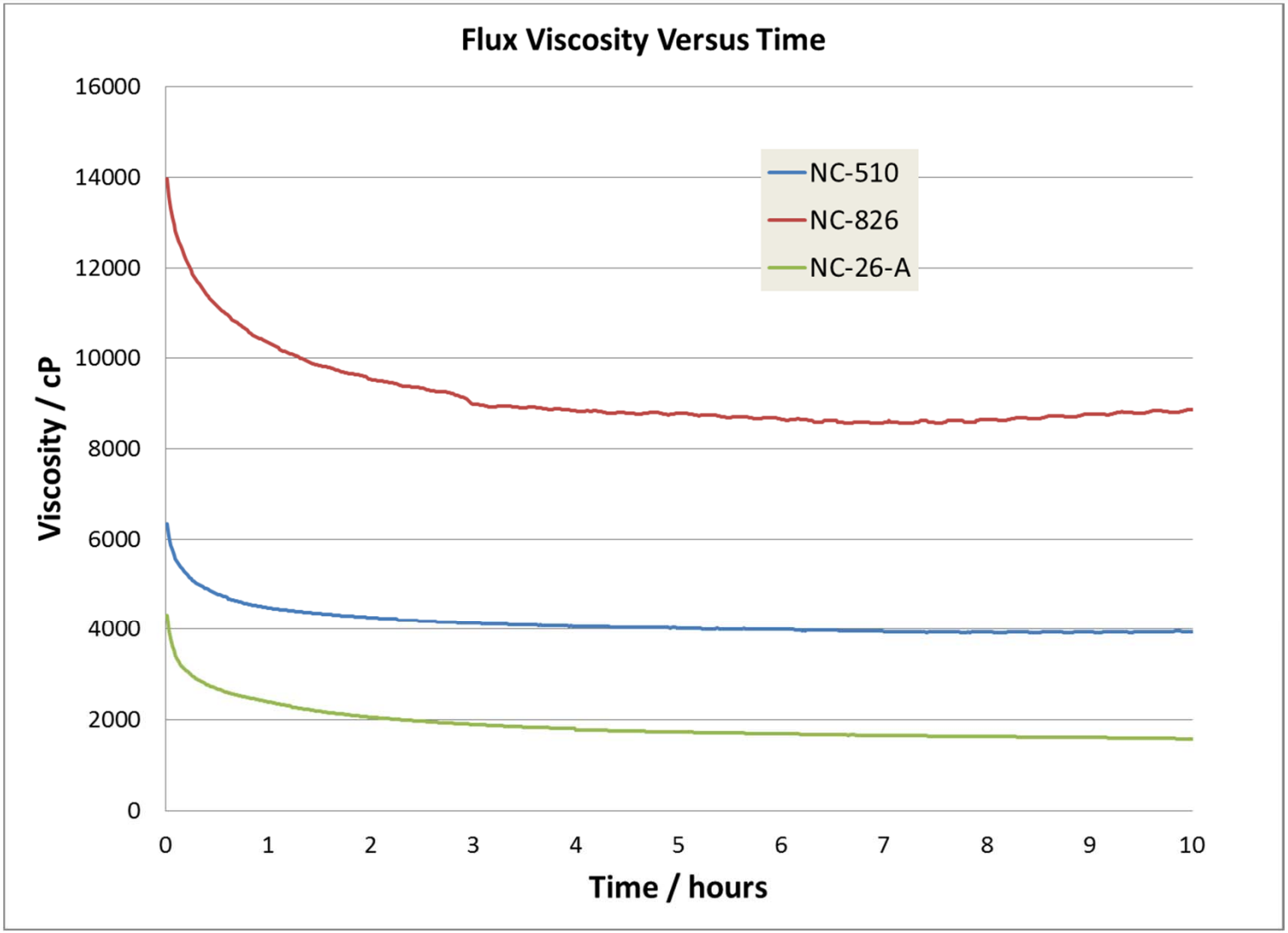
High residue

TGA: Ultralow Residue (ULR) and Standard Residue Flux Types

TGA is unrepresentative of real situations for flux. The exposed surface area is much smaller in TGA is smaller than for real flip-chip applications. In reality, flip-chip fluxes will have lower residue levels than shown here.



Comparative Viscosities as a Function of Time

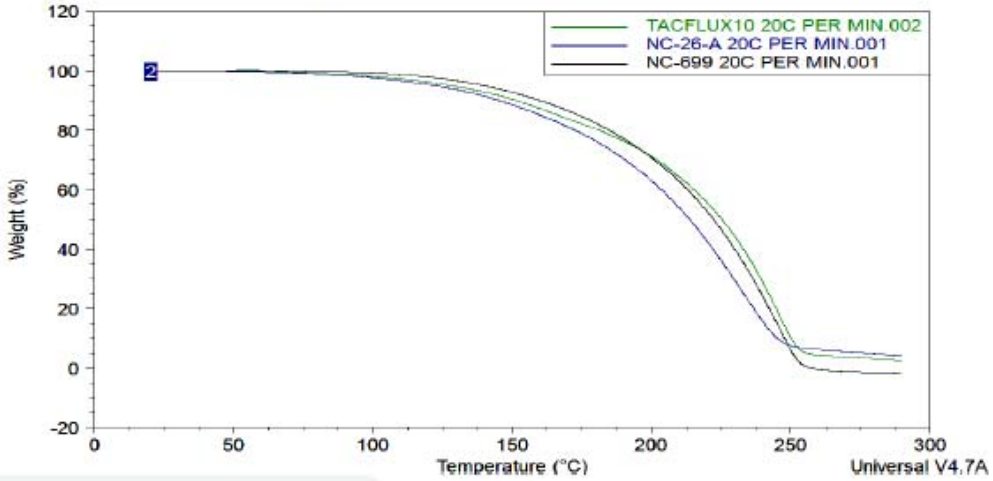


TGA and Wetting Test

TGA:

- TGA analysis was done with 20C/min rate.
- Tacflux 10 and Flip-Chip Flux NC-26A are similar in residue level.
- NC-699 has less residue than the other two fluxes.

TGA Thermogram



Wetting Test: **Solder Height**(mm) after reflow. Higher reading is worse in wetting.

	Tacflux 10	Flip-Chip Flux NC-26A	NC-699
average sphere height	0.80	0.76	0.75

Reflow under N_2 Environment using Typical SAC Reflow Profile with 90mil (2.29mm) diameter sphere. Substrate is OSP. Flux was printed using 0.25mm thick and 6.4mm diameter opening stencil.

Wetting Test Result:

- Flip-Chip Flux NC-26A and NC-699 are similar in wetting performance.
- Tacflux 10 performs slightly worse than the other two fluxes.

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Portfolio of No-Clean Semiconductor Fluxes

		Indium Corporation Semiconductor Grade Flux Materials							
Aspect	**Condition**	**Flip-Chip Flux NC-510**	**Flip-Chip Flux NC-26-A**	**Flip-Chip Flux NC-826**	**704-24-8**	**Developmental Material**	**Developmental Material**	**699-34-1**	**749-030A****
Target Final Device	Chip type and usage	MEMS / flip-chip general use	Flip-chip	Flip-chip	Flip-Chip	Flip-Chip	Flip-Chip	MEMS	MEMS
Primary Application	Usage in chip assembly	MEMS and <60µm pitch standard flip-chip	Flip-chip and copper-pillar flip-chip > 100µm pitch	Copper pillar <= 100µm pitch	Copper pillar <= 100µm pitch with TCB	Copper pillar <= 100µm pitch with TCB	Copper pillar <= 100µm pitch with TCB	<1mm2 devices with 4-8 I/Os 60-80µm diam	>1mm2 devices with 8-24 I/Os 60-80µm diam
Reflow Type	<100ppm oxygen in nitrogen is standard for inert reflow	Mass reflow	Mass reflow / TCB	Mass reflow	TCB	TCB	Mass reflow	Mass reflow / TCB	Mass reflow
Method of Application	Usage in tool	Dipping / printing	Dipping	Dipping	Spraying	Spraying	Dipping	Dipping	Dipping
Residue Level	Varies with reflow profile / die size and clearance	ULR	ULR	LR	NZR	NZR	ULR	NZR	ULR
Solder Alloy Compatibility	Eutectic (SnPb37) and Pb-free (tin/silver)	Both	Tin/silver	Tin/silver	Tin/silver	Tin/silver	Tin/silver	Tin/silver	Tin/silver
Surface Metallizations	Issues/incompatibilities	-	-	-	-	Rapid OSP removal	Target for OSP removal	-	-
Polymer compatibility	Underfill types	Compatible with majority of CUF and MUF	Still to be proven. Reflow / flux "cure" process will govern compatibility	Still to be proven. Reflow / flux "cure" process will govern compatibility	Still to be proven. Likely to be excellent.	Compatible with MUF for rapid (<5sec / unit) assembly (Target)	Compatible with majority of CUF and MUF (Target)	Unknown	Unknown
Halogen-free	Ion Chromatography	Yes	Yes	Yes	Yes	Yes (target)	Yes (target)	Yes	Yes
SIR Testing	IPC-J-STD-004A	Pass	Pass	Pass	Pass	Pass (target)	Pass (target)	Pass	Pass
Status of Flux Manufacturing		Volume manufacturing	Volume manufacturing	Scaled-up and ramping	Lab phase only	-	-	Volume manufacturing	Scaling up
Customer Approval		Yes: multiple	Yes	Yes	Yes	-	-	Yes	Yes
Customer Volume Usage		Yes: multiple	Small volume for specific devices	Ramping	Not yet	-	-	Small volume for specific devices	Ramping
	(+) Conforms to IEC 61249-2-21								

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Epoxy Flux

Epoxy Flux - Design

- Indium has formulated a number of different Epoxy Flux products. These were initially designed for to mount:
  - Flip Chip
  - CSP;
  - BGA, and;
  - PoP

  components to improve drop test reliability.

  (~4x improvement in drops to failure typical)

Epoxy Flux – Benefits

- In addition to improving drop test performance, Epoxy Flux usage:
  - Eliminates the need to underfill and post-cure components;
  - Improves thermal cycling performance, and;
  - Increases component shear strength
    - ~50% - 100% increase typical.

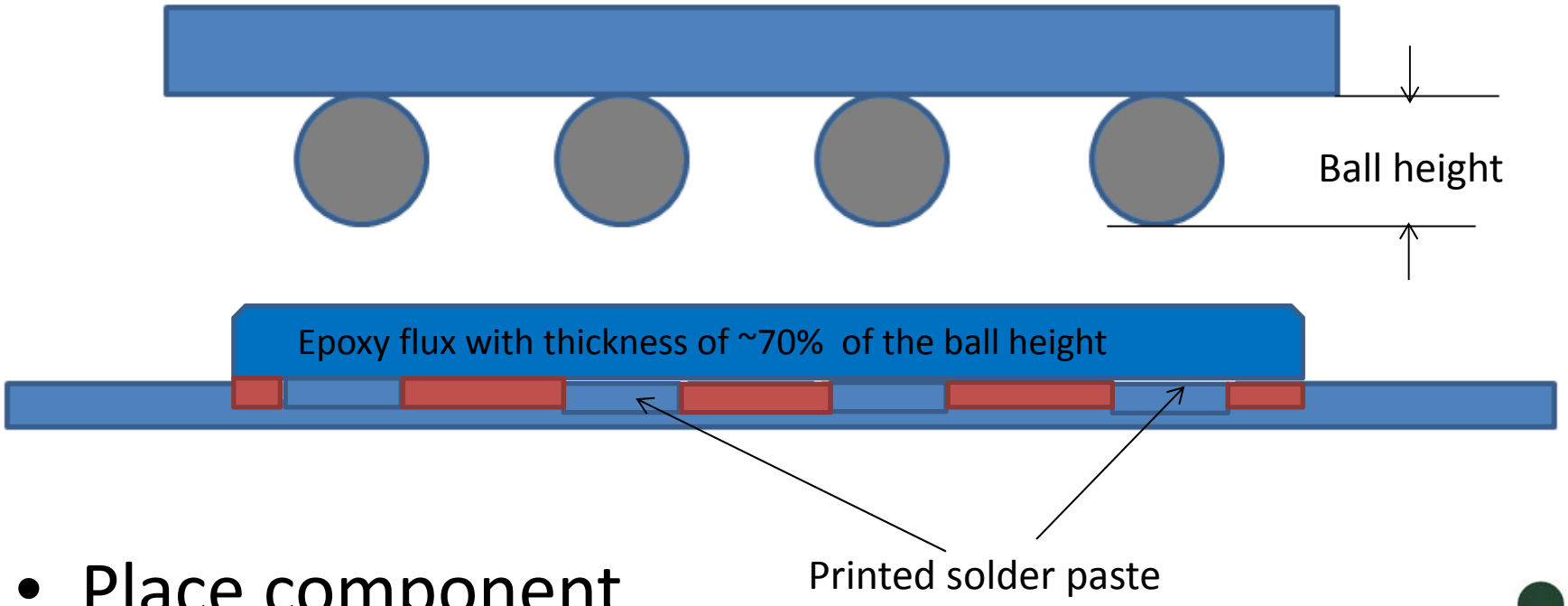
Epoxy Flux – Application

- Epoxy Flux products can be applied by:
  - Jetting;
  - Dispensing;
  - Printing and;
  - By hand (i.e.: for re-work).

- Dipping may also be used in proof-of-concept evaluation, but higher precision application methods are preferred.

FC Mount with EF - Pictorial

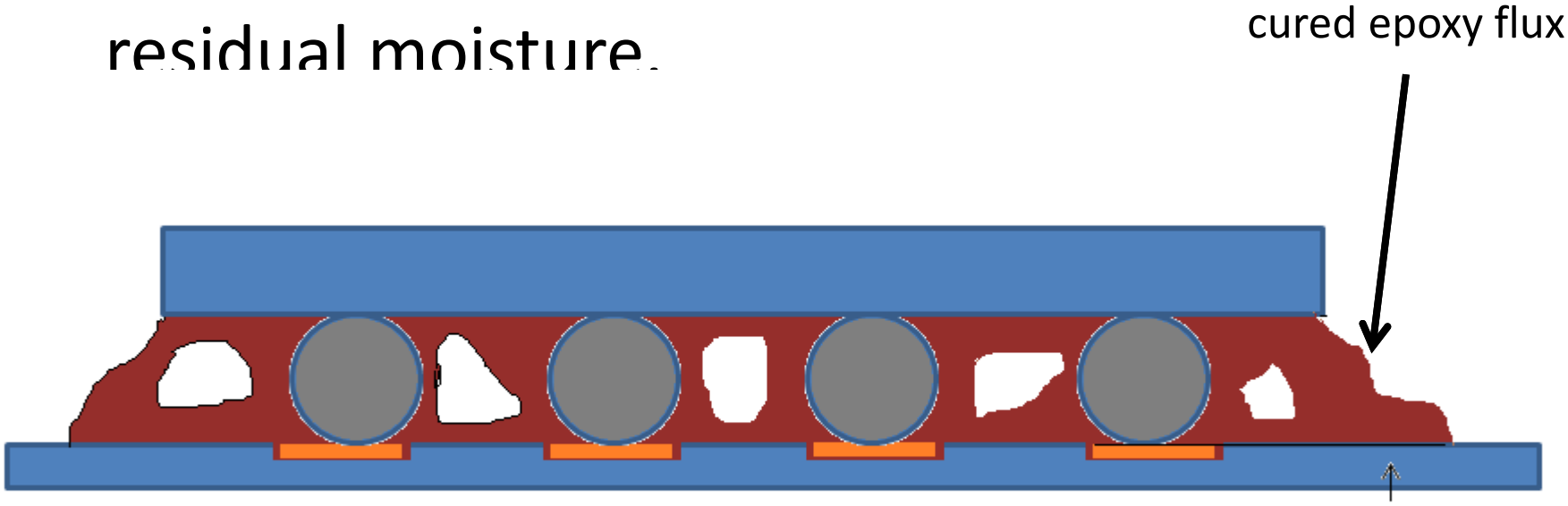
- Apply Epoxy Flux (with or without solder paste)



- Place component

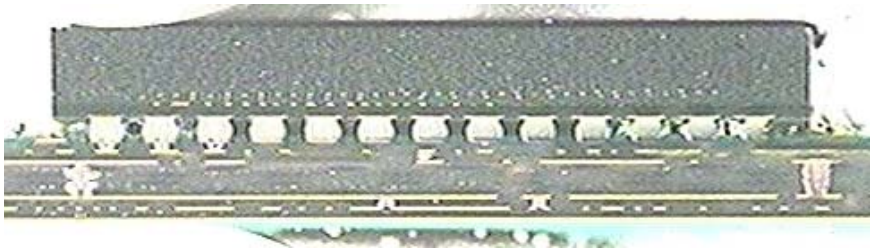
After Reflow

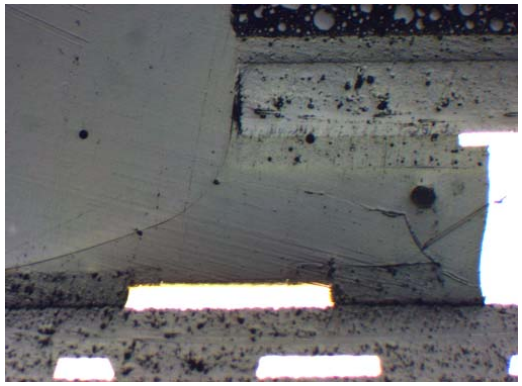
- Cured Epoxy Flux contains venting channels to facilitate the removal of fluxing residues and residual moisture.

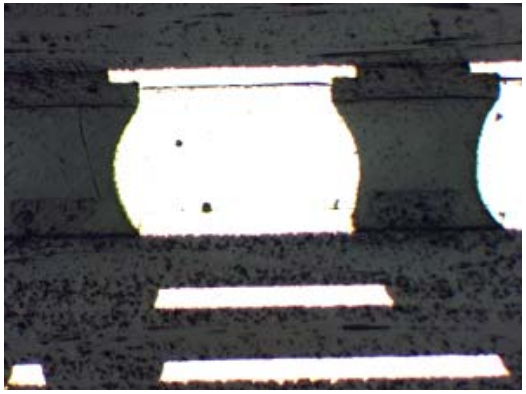


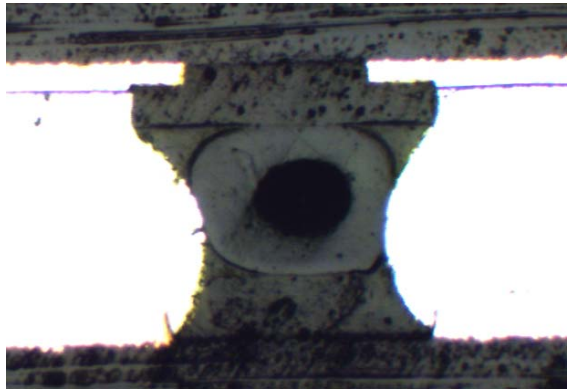
Cross-section of Joints

Excellent wetting (center, right), fillet (left), typical bump shape (middle), and some EF outgassing channels (right). Use 650-48









Indium 719-88

solder ball mounting & flip chip attachment epoxy flux, cure condition are good for highly crosslinked system

- This special epoxy flux is designed with multiple reflow application for ball mounting.
- This product need special reflow profile with four stages heating oven (SIKAMA moving hot plates): 170-220-260-170 with 40 second per hot stage.
- After cure, this product has very high strength and compatible with sequential reinforcement polymers such as under-fill, encapsulation as well as molding compound. Comparing to the convectional flux which left sticky residue, 719-88 provide solid bonding foundation.

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Epoxy Flux 719-88 for solder ball mounting / flip chip attachment

- This special epoxy flux is designed with multiple reflow application for ball mounting and flip chip attachment. This product can be reflowed with four zones conduction heating oven (such as SIKAMA): 170C-220C-260C-170C with 40 second per heating zone. After cure, this product has very high strength. It can also be compatible with sequential reinforcement polymers such as under-fill, encapsulation as well as molding compound. Comparing to the conventional flux residue, the thermoset epoxy flux 719-88 provide solid bonding foundation.

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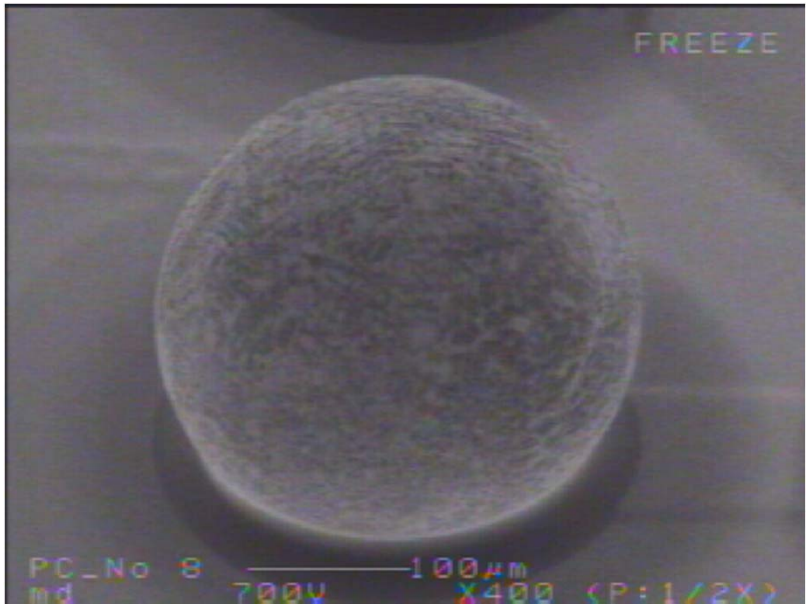
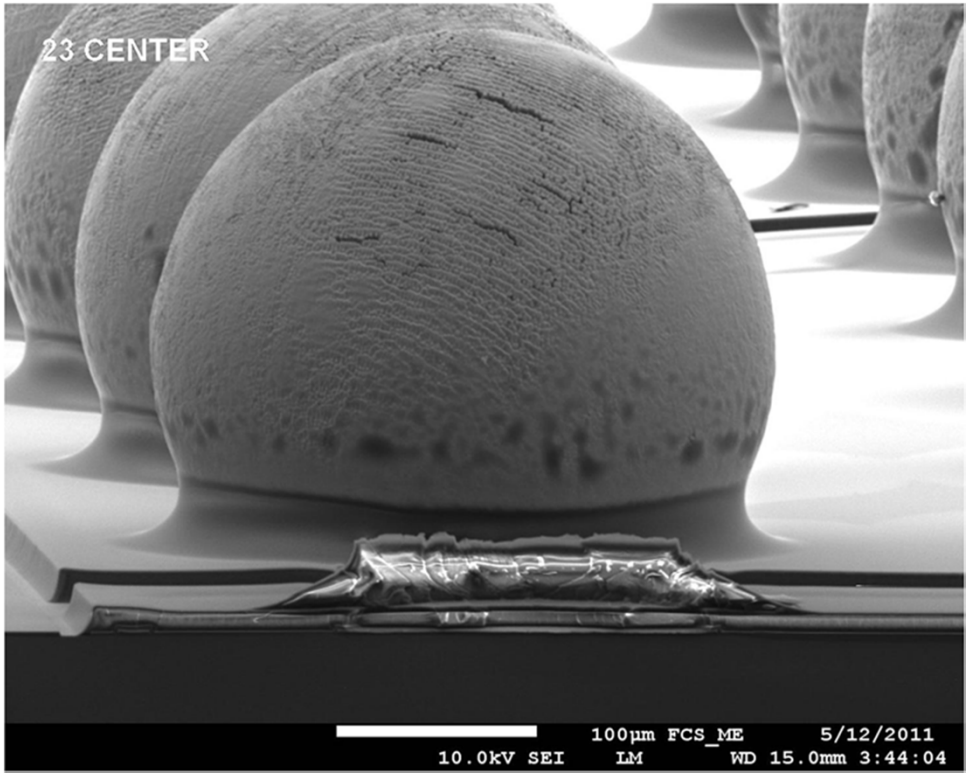
It form hard collar after installation





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719-88 DSC

Sample: 719-88

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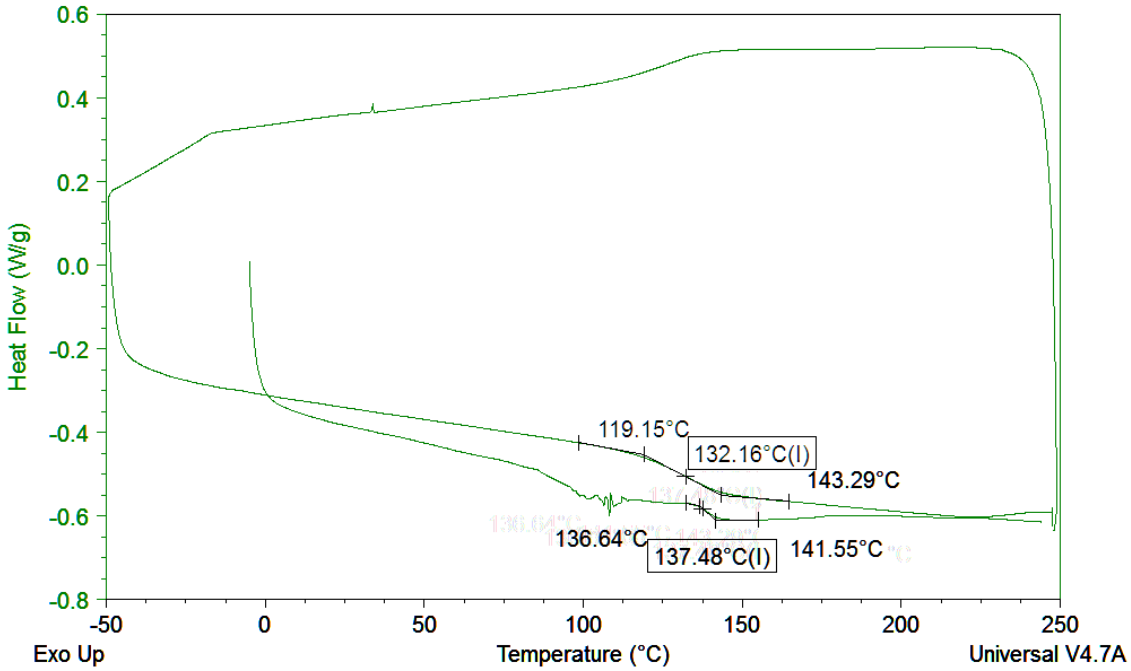

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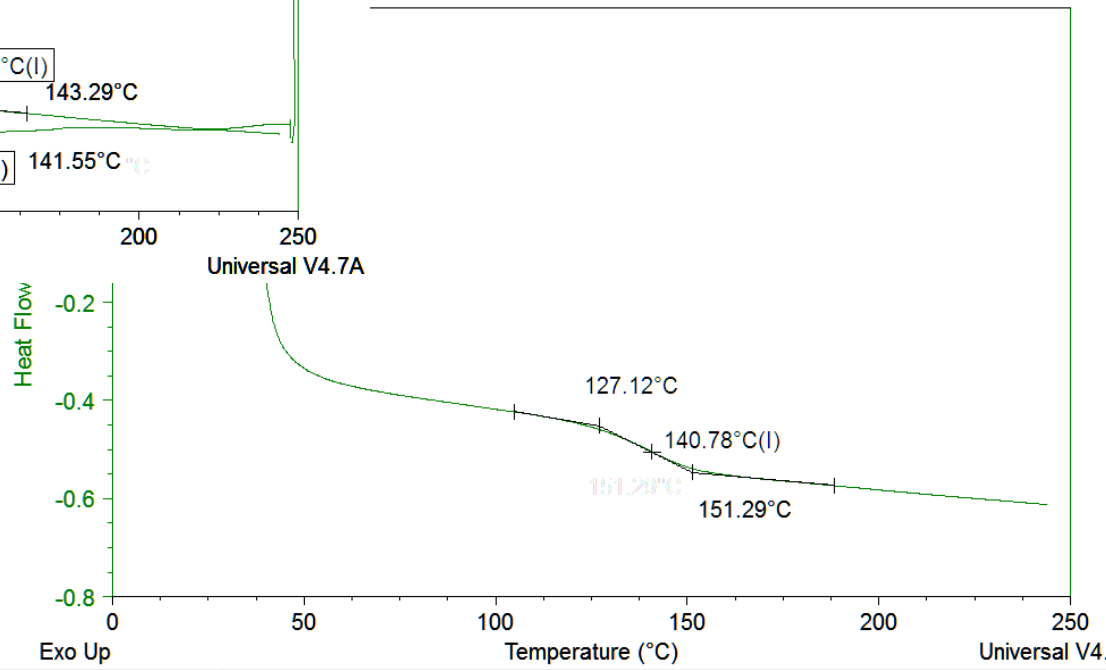

Epoxy Flux 719-88 for solder ball mounting/flip chip attachment

Application Method

Printing process is generally used for most ball mounting and flip chip attachment. Jetting is preferred because the precise amount of epoxy flux could be deposited. Dipping can also be used for flip chip attachment.

Tg DSC method, cured	About 71.0°C (depends on cure condition)
Tg After multi-reflow (maximum)	140°C, (material getting soft above Tg)
Typical Viscosity (Brookfield, Model HB DVII-CP)	7000 - 9000 cps, 20 rpm, 25°C
Shelf life (at < -15°C)	6 month
Pot life (at room temp.)	3 days viscosity increase less than 10%
Surface Insulation Resistance (Ohms) (J-STD-004), logarithm	>10.0 after 7 days at 85°C, 85% humidity, 7 days
Flux activation temperature	170 °C

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What is Cooking ?
- Epoxy Flux 756-59

756-59 is a very strong epoxy flux under development. It is targeting to work for flip chip attachment and very resilient material property. In this formulation, it maximized resin, epoxy and acid content and minimized solvent, thus provides maximum solid reinforcement.

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UV Curable Solder Flux For Ball Mounting

- SMT have BGA that epoxy flux was covered by component and UV cannot get in under the package.
- But ball mounting process have flux exposed for UV irradiation. Ball mounting is a perfect situation that UV curable flux could be used as secondary cure mechanism.

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Dual Cure Formulation
Dual Function

- Thermal epoxy and uv curable acrylate mixed together.
- Flux chemistry mix with curable materials,

  di-functional chemicals for crosslinking two chemistry.
- Finish flux work, then cured by heat, further strengthen by UV light cure.

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Market and application

- Easy to apply, screen printing, spin coating, etc., fit all traditional equipment's.
- Multi functionality, ball mounting, wafer or chip protection film, solder strengthening,…..
- Extra equipment required is only a UV light cure unit, less than $10,000/unit
- Fast post UV cure, less than one second.
- No premature cure will happen (this is a major problem for formulation with good properties).
- No dipping process involved (which is a major hurdle for epoxy flux).
- Patentable, we will be the only player in this field.
- Huge potential market, maybe larger than epoxy flux.
- Higher profit margin in semiconductor industry

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